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Analysis of Major Accidents Reported to the MARS Database During the Period 1994-2004

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Executive Summary

The analysis of past accidents in process industries is a useful method for identifying common aspects regarding the causes that triggered such accidents. The Major Accident Hazards Bureau of the European Commission's Joint Research Centre (JRC) has a long tradition in the analysis of "major accidents" reported to the MARS database in accordance with the Seveso II Directive requirements. This report presents the results of the analysis performed on a series of accidents reported to the MARS database. The analysis is limited to those events reported as major accidents occurred in EU 15 countries during the period 1994-2004.

The objective of the present report is to obtain trends in the evolution of the accidents for the period analysed, as well as to establish relations between different aspects regarding the accidents studied. In particular, the aspects on which the present analysis has focused are:

- Evolution of the number of major accidents per year.
- Consequences of the accidents, in terms of overall fatalities and number of people injured outside the establishment concerned.
- Types of industries involved in the accidents as stated in the MARS reports.
- Physical consequences resulting from the accidents.
- The main chemical substances involved in the accidents.

The previous items have been interrelated in an attempt to establish correlations between the different parameters. For instance, for each type of industry studied, the number of accidents involving human fatalities per year will be shown, specifying what were the physical effects and the chemical substances involved. The main parameter of interest selected to highlight the accidents analysed has been the number of fatalities or injuries outside the industrial establishment, but other parameters included in the MARS reports such as economic losses or environmental damage could also be used for similar analyses in the future.

The analysis performed shows that there is a cyclical oscillation in the number of accidents reported to MARS since the implementation of the Seveso II Directive in 1996. Since that date, there appear to be periods of 3 years in which there is a progressive decrease in the number of accidents, with an abrupt increase of reported events at the end of each cycle. The present analysis also proves that accidents involving explosions are the ones that generate the most severe consequences, even though for certain types of industries, fires are of greater concern. On the other hand, accidents creating disturbances for the external population are usually related to toxic releases of general chemical products such as ammonia or hydrogen chloride. This report quantifies the accidents of each type that have been reported to MARS and shows their evolution over the years in the period analysed.

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1. Introduction.

The analysis of past accidents in process industries is a valuable system to identify common aspects regarding the causes that triggered such accidents. The Major Accident Hazards Bureau (MAHB) of the European Commission's Joint Research Centre (JRC) has a long tradition in the analysis of major accidents reported to the MARS database (MARS, 2005) in accordance with the Seveso II Directive requirements (Council Directive, 1996). Some of the analyses performed in the past concerned common causes and general lessons learned (Drogaris, 1993; Kirchsteiger, 1999; Mushtaq and Christou, 2004) whereas others were focused on specific situations (Christou, 1999; Sales *et al*., 2007). In this paper we intend to establish possible trends in the evolution of the accidents occurred in the European process industries in the recent past, as well as to establish which are the most common chemical substances involved in those accidents. The period chosen for the analysis comprises the years 1994 through 2004, which includes the elaboration of the Seveso II Directive in 1996, its implementation in the different Member States and the elaboration of the amendment to the Directive in 2003. The analysis is limited to major accidents[1] that occurred in EU 15 countries for the period previously mentioned.

2. Analysis of the accidents.

There are various issues that have been studied in the present report. The main goal is to determine the evolution of accidents in Europe in the recent past related to the type of industry, the consequences generated (both on-site and off-site), the physical effects associated to the accidents and the chemical substances involved.

2.1. Number of accidents.

A total of 301 major accidents were reported by EU 15 countries for the period 1994-2004. Figure 1 shows the number of accidents per year for the mentioned period.

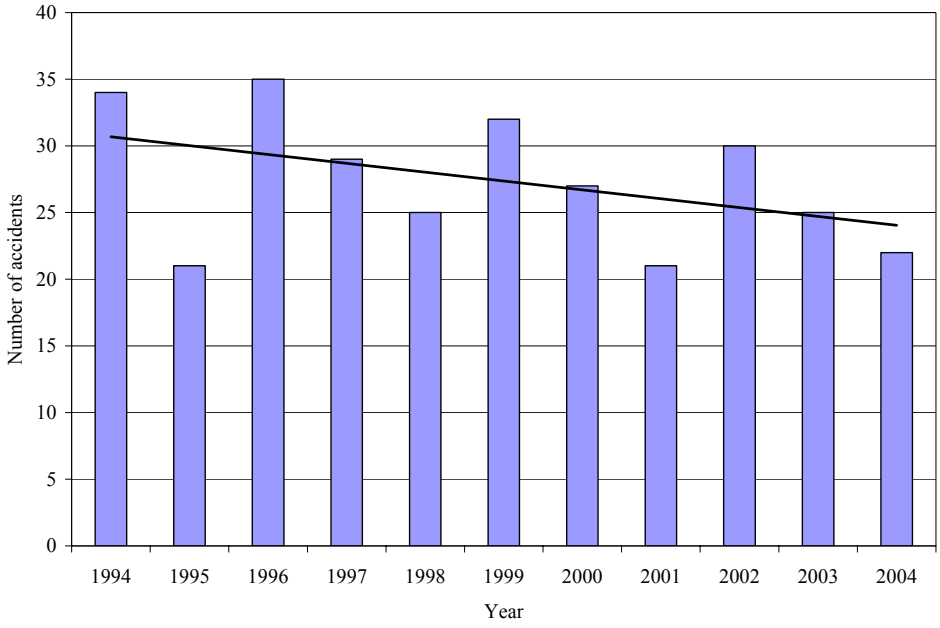

Figure 1. Number of accidents per year for the period 1994-2004.

[1] The MARS database includes not only major accidents reported according to the criteria established in Annex VI of the Seveso Directive, but also near misses and other events reported by OECD member countries.

From the previous figure, it can be seen that there is a tendency which indicates that the number of major accidents is being reduced. Moreover, there seems to be a trend starting from the year 1996. According to that trend, accidents could be grouped in periods of three years. In each group, the number of accidents decreases, but at the beginning of the next cycle (1999, 2002) there is an abrupt increase in the number of accidents. However, an overall decrease in the number of accidents seems to be hinted comparing the first (1996-1999-2002), second (1997-2000-2003) and third (1998-2001-2004) respective years of each cycle. The only exception is found in the year 2004, in which there was one more major accident reported compared to the year 2001.

This trend suggests that the evolution of safety in process industries is cyclical, probably related to variations in risk perception or awareness. This can be due to an increase in risk awareness after a relevant accident (like those occurred at Toulouse, France in 2001 or Enschede, the Netherlands in 2000) or to recent legislation for each period (like the implementation of Seveso II Directive). Then, at the end of such period, some companies may fall into a sense of overconfidence and relaxation regarding safety management, and the number of accidents starts increasing again.

2.2 Main consequences of the accidents.

Figure 2 shows the number of accidents that reported at least one fatality and the number of fatalities generated by the accidents, compared to the total number of accidents reported as shown in Figure 1. A total of 63 accidents had one or more fatalities, whereas 153 people died as a consequence of those accidents.

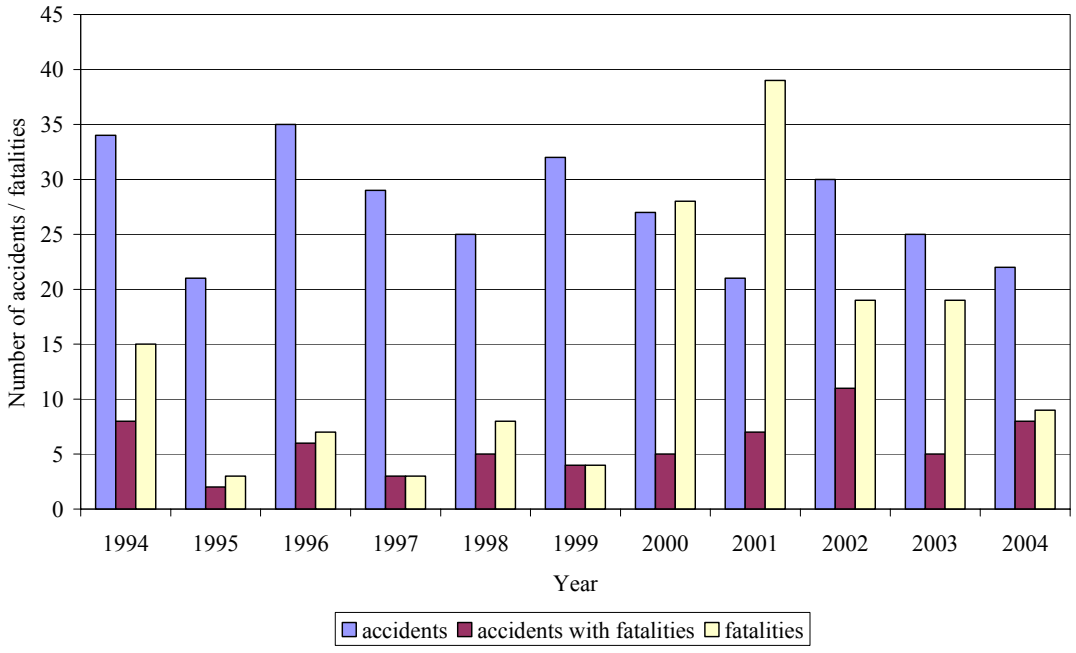

Figure 2. Comparison of the number of accidents, number of accidents with fatalities and number of fatalities.

It can be seen that from the year 2000 there has been an increase in the number of fatalities. The high numbers of fatalities shown for the years 2000 and 2001 correspond in great measure to the accidents that happened in Enschede and in Toulouse, which were key events for launching the amendment of the Seveso II Directive. It can also be seen that the number of fatalities in the years 2002 and 2003 were higher than in any of the other years of the 1990's. The number of accidents reporting fatalities

increased constantly for the period 1999 and 2002, being this last one the year with more accidents with fatalities, a total of 11, for the whole period analysed.

These figures show that despite the progressive reduction in the number of major accidents, the consequences generated by such events that are still happening in process industries are serious enough to continue the efforts of improving safety in European process plants. There may be various reasons for this. Some of the factors contributing to more serious accidents could be the growing tendency in process industries to operate in larger plants, hence having a greater concentration of people. Moreover, there is also a tendency of increasing the number of contractors employed for routine operations such as maintenance. People external to the establishment are usually less aware of the hazards involved in the processes, and their training becomes more difficult for the industries. A similar tendency is related to the movement of personnel. In the past, it was common to have people working in the same plant for a large number of years, however nowadays it is typical that workers will work at different establishments for shorter periods of time. The migration within Europe also leads to foreign workers being employed in other Member States, creating language difficulties for understanding the details of hazardous processes.

Figure 3 shows the F-N (Frequency-Fatalities) curve of the number of fatalities in process industries for the period analysed. This curve represents the frequency F with which accidents of N fatalities or more occurred among accidents with at least 1 fatality (i.e. $P[x \geq N \mid N \geq 1]$).

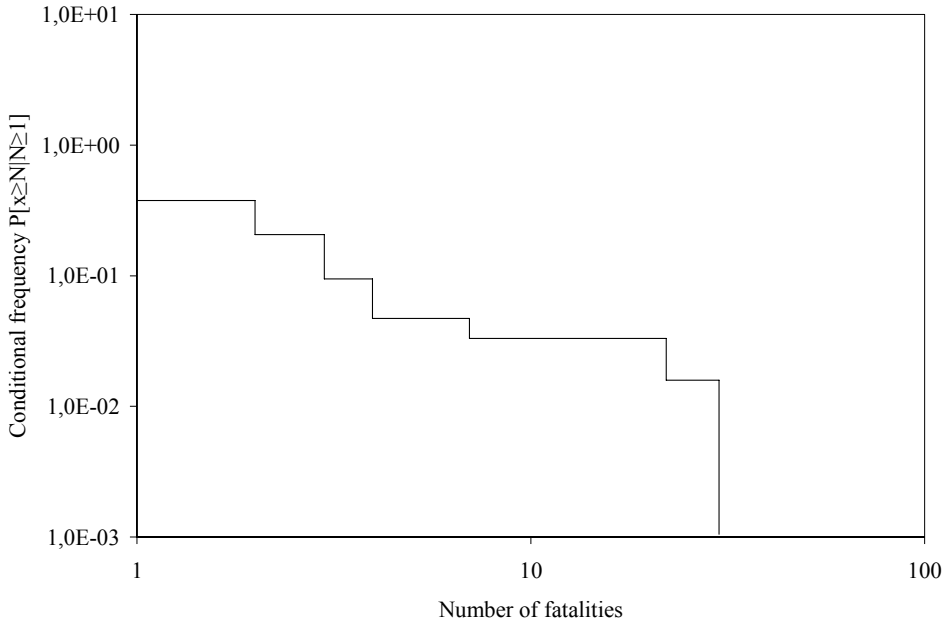

Figure 3. F-N curve for number of fatalities.

Another important factor, apart from the number of fatalities generated by the accidents, are the consequences to the population outside an establishment. Impact of accidents is the main reason for the negative image of chemical and process industries in modern society.

5 accidents reported fatalities outside the establishment. These include the cases of Toulouse in 2001 and Enschede in 2000, another accident with 1 fatality in 1994, and two accidents in 1998, one reporting 1 fatality and other reporting 4, all workers in a tug boat at a port area. However, the high number of reported injuries off-site gives an indication of the gravity of the accidents. 3792 people external to the plants were injured in major accidents according to the MARS data (406 without including the numbers reported for the Toulouse and the Enschede tragedies).

At this point, some remarks on the information of the MARS reports must be made. This information comes directly from the Competent Authorities of each Member State of the European Union. Clearly for outside consequences it is sometimes difficult to determine how many people were affected by, for example, a toxic cloud spreading in a inhabited area. In some reports, expressions like 'some people complaining of respiratory problems' are used, without specifying the exact number of people affected. This happened for instance in the only accident reporting consequences off-site in 2003, so a value for injuries off-site cannot be given. In a total of 4 accidents for the period analysed the number of people injured off-site was not given, and in 3 cases the numbers given were approximate (e.g. 'around 80 people suffered breathing problems'), in which case the number reported was used for the analysis.

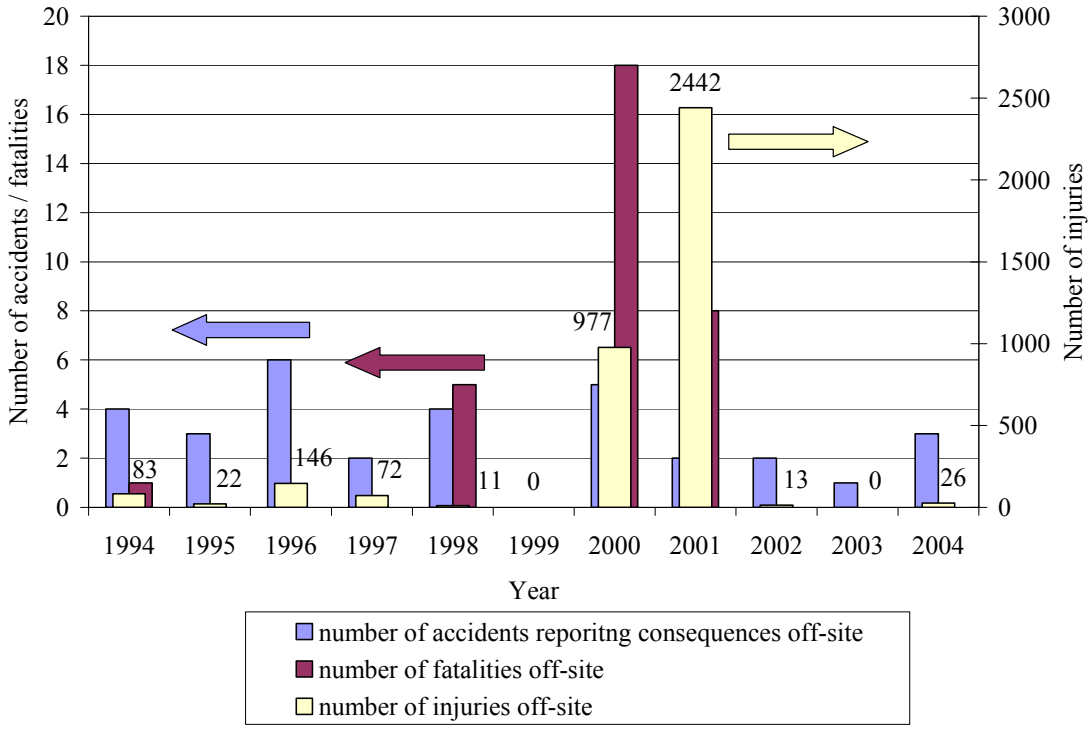

Figure 4. Accidents reporting consequences off-site; showing number of injuries off-site.

2.3. Type of industries involved in the accidents.

It is interesting to determine what kinds of establishments are more likely to suffer major accidents and what the main characteristics of accidents reported for each industry type are. Figure 5 shows the number of accidents that happened during the period analysed, grouped by different types of industries. The type of industry must be indicated, selecting one of the categories seen in Figure 5 when reporting an accident to MARS.

General chemicals manufacture is the type of industry with the highest number of accidents (100), and it is related to production of basic chemicals that do not fit in any of the other categories. Petrochemical installations (e.g. refineries) had 50 accidents, and wholesale and retail storage is the third category with more number of accidents (26), and it is related basically to warehouses, including LPG bottling and bulk distribution.

Figure 6 shows the number of accidents with fatalities and total number of fatalities for the main industry types shown in Figure 5, while Figures 7 through 14 show in detail the evolution of accidents and their consequences over the period analysed.

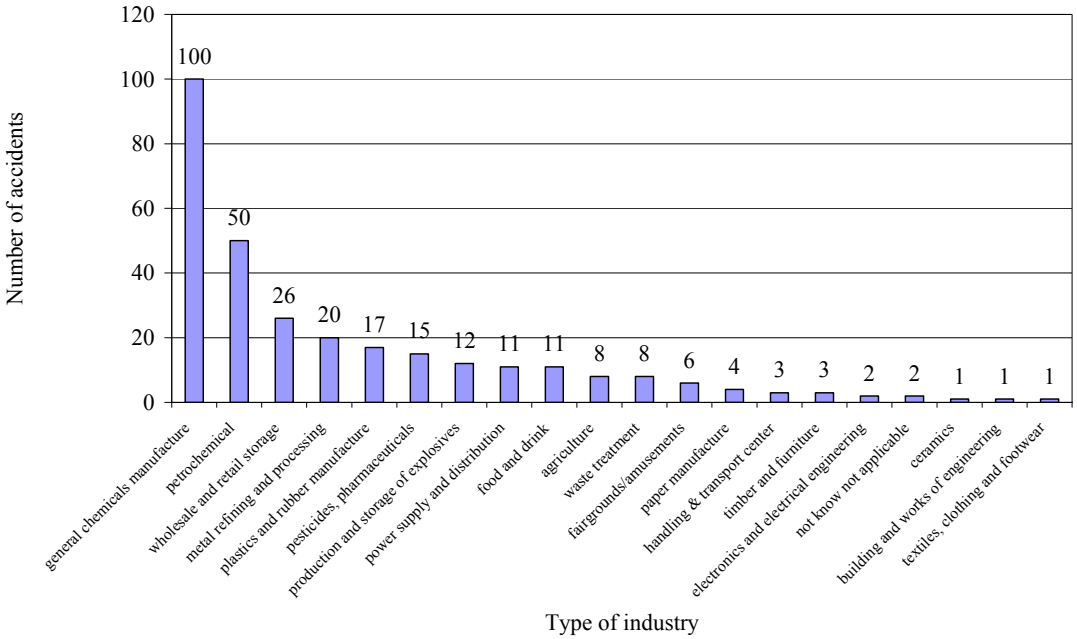

Figure 5. Number of accidents per type of industry for the period 1994-2004.

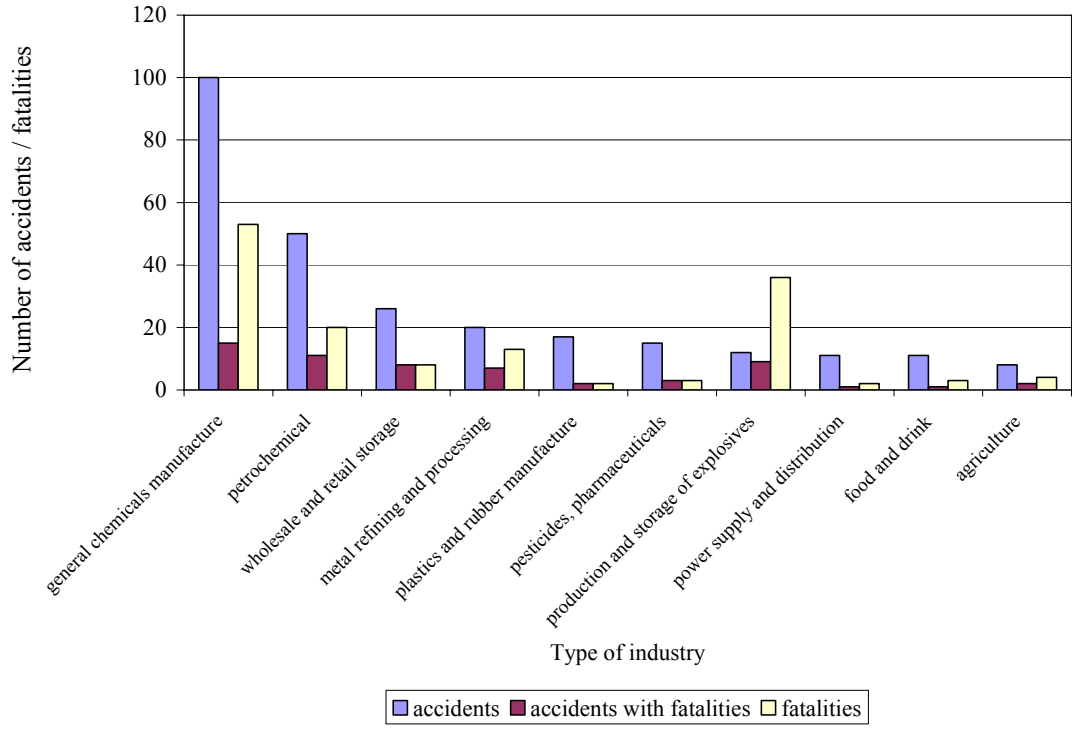

Figure 6. Comparison of the number of accidents, number of accidents with fatalities and number of fatalities for the most relevant types of industries.

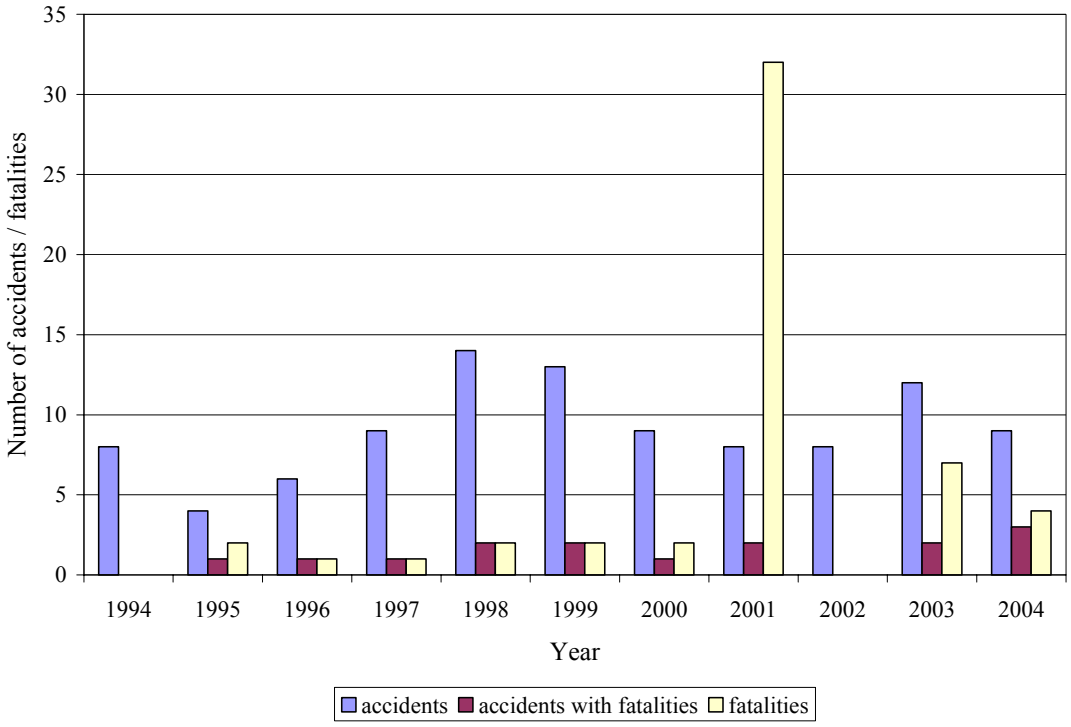

Figure 7. General chemicals manufacture

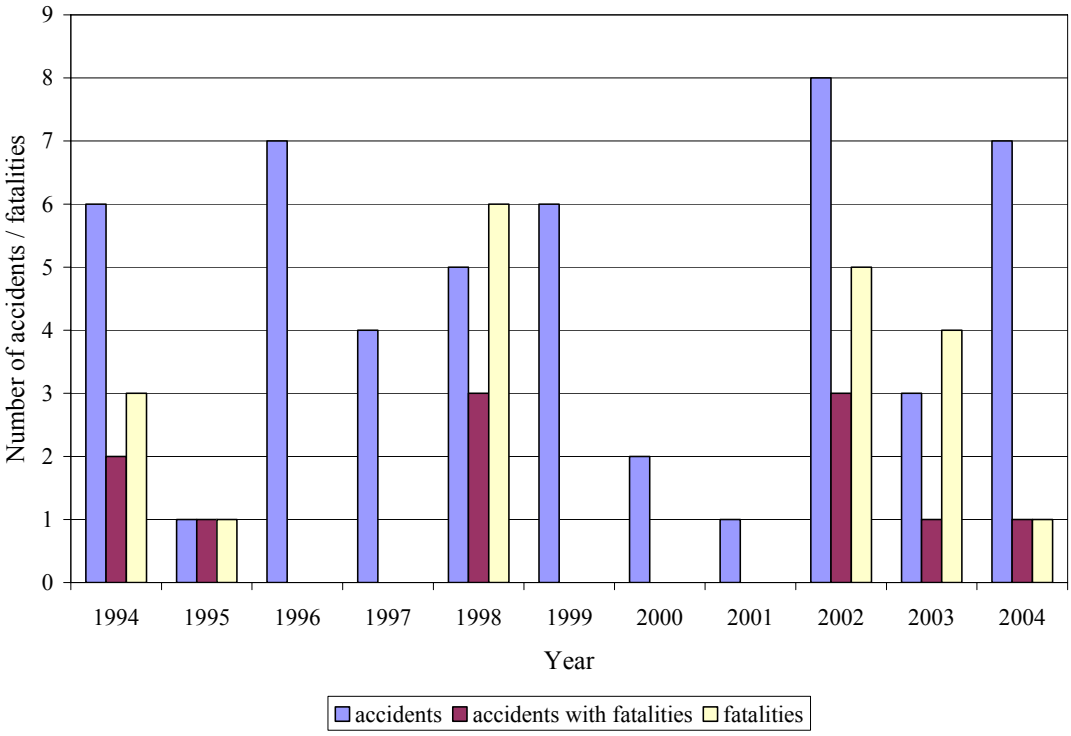

Figure 8. Petrochemical

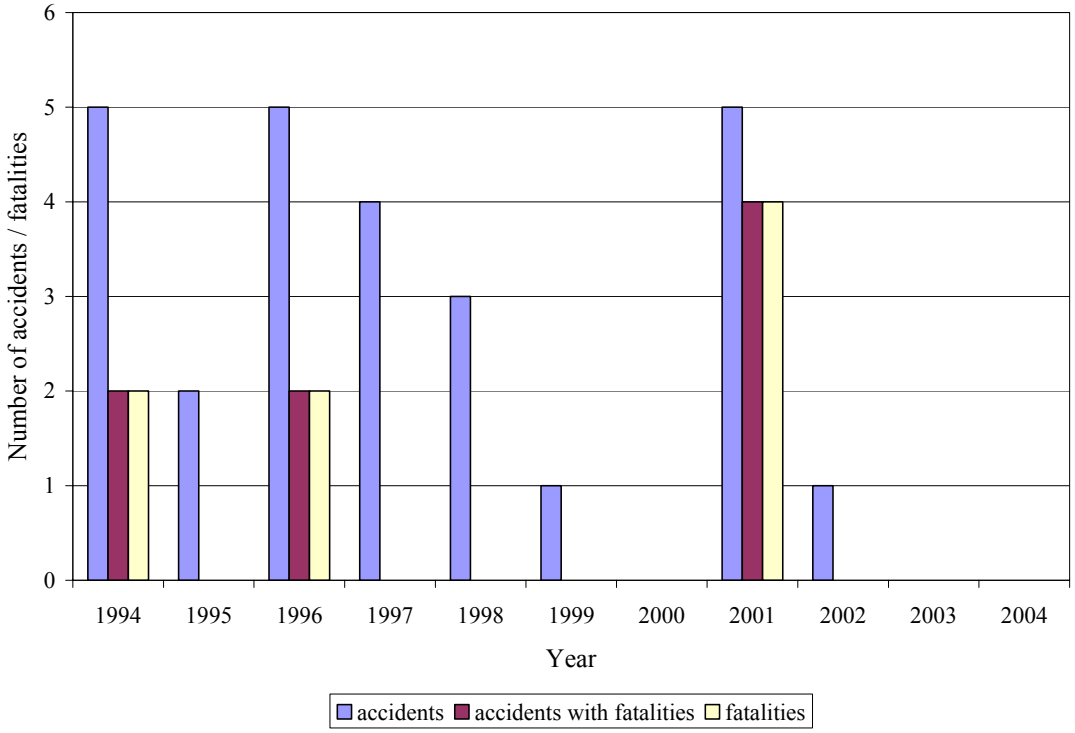

Figure 9. Wholesale and retail storage

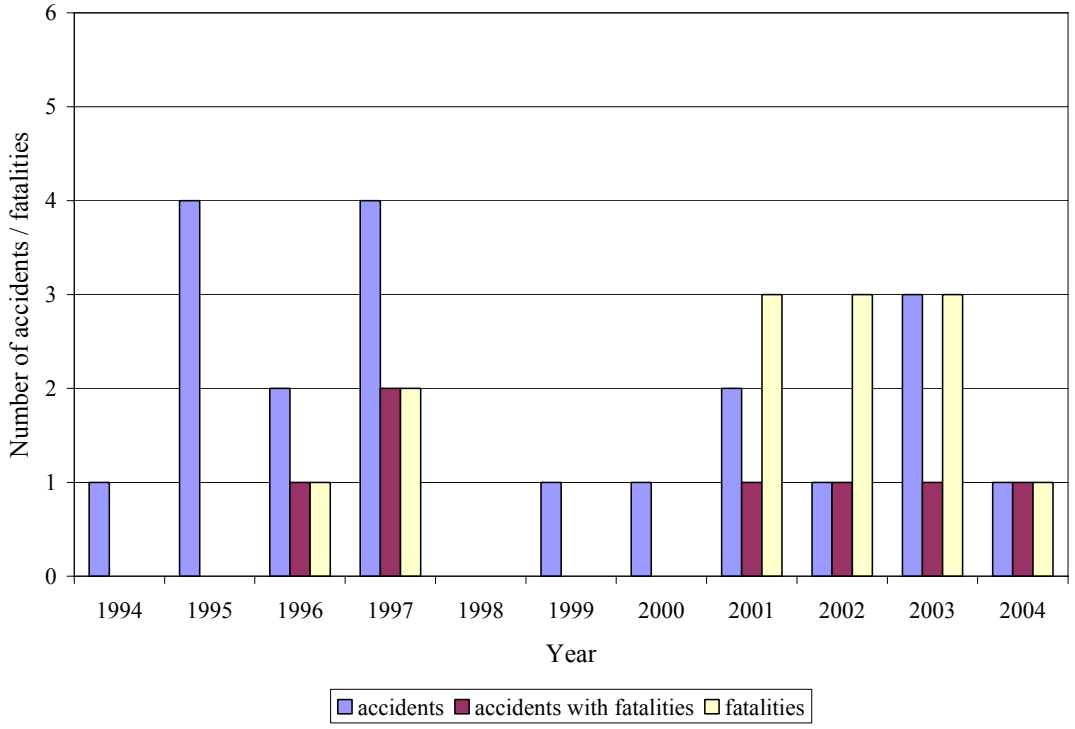

Figure 10. Metal refining and processing

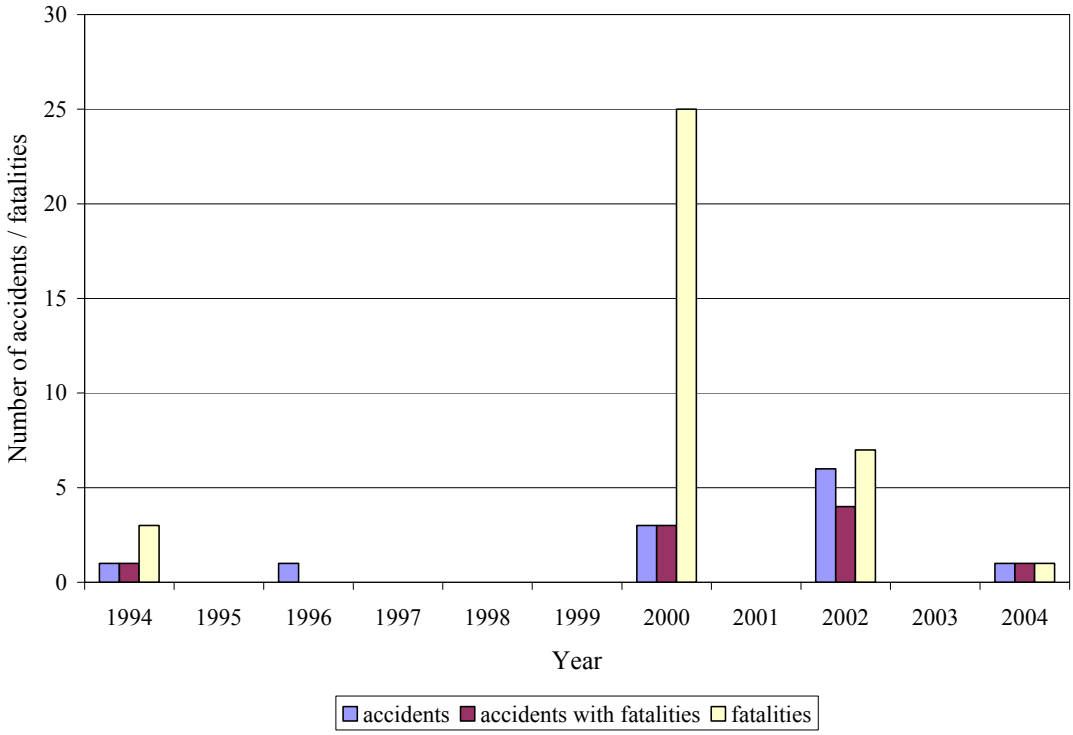

Figure 11. Production and storage of explosives

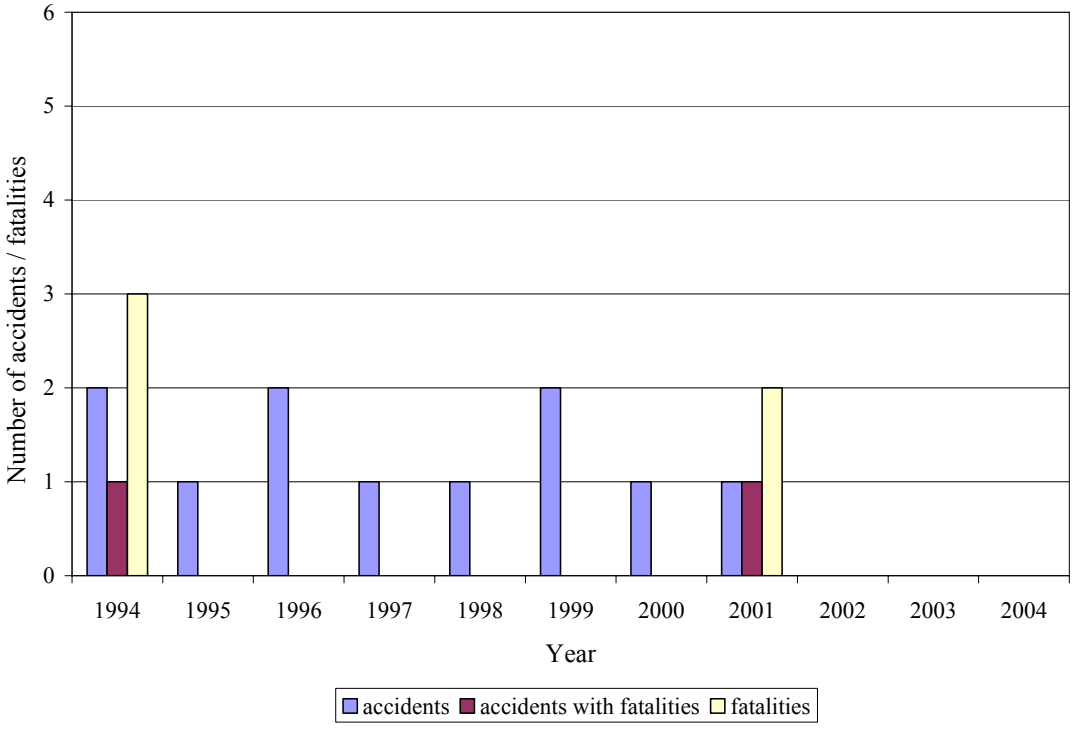

Figure 12. Food and drink

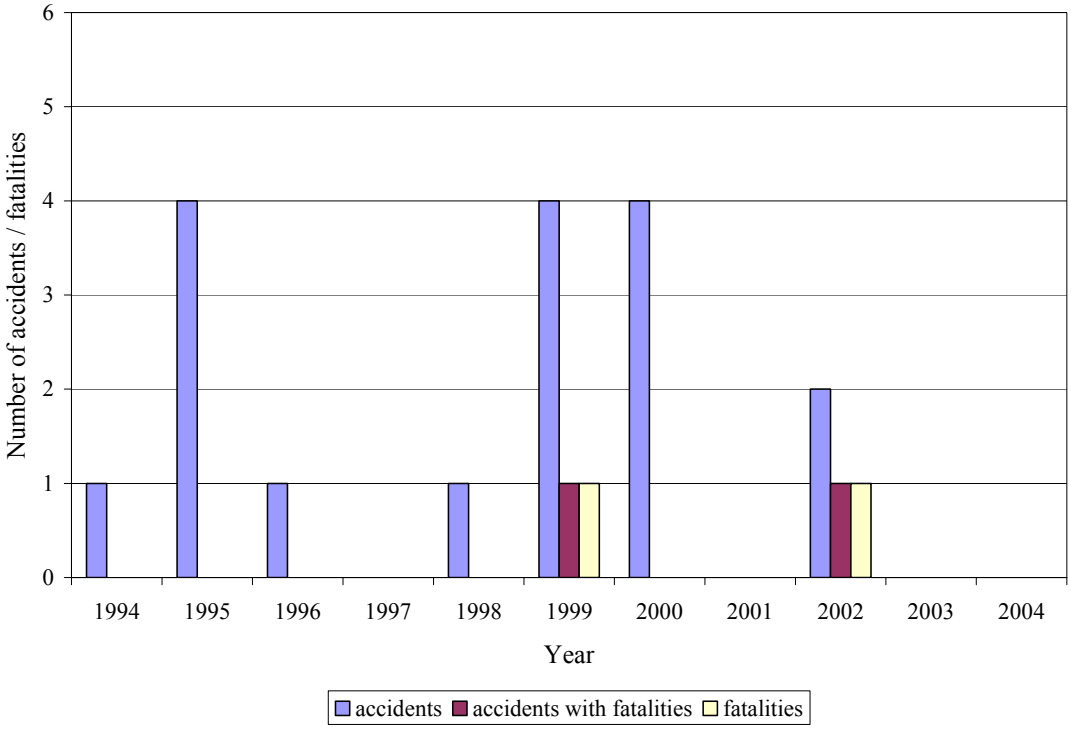

Figure 13. Plastics and rubber manufacture

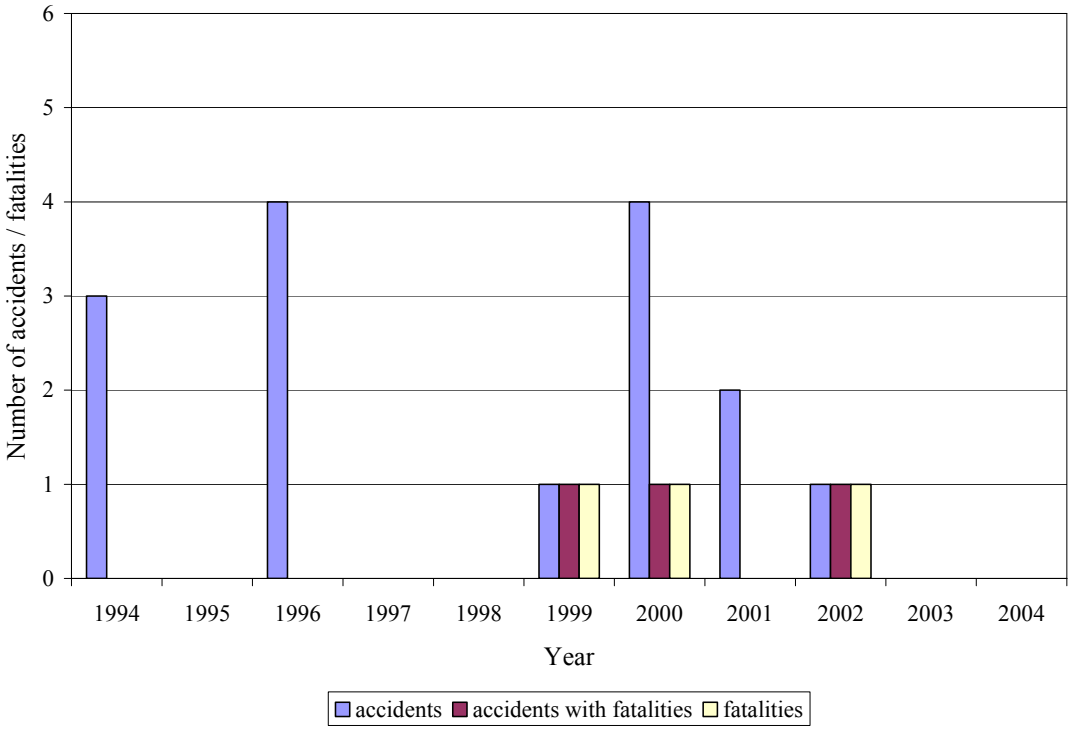

Figure 14. Pesticides and pharmaceuticals

The results from the Figures shown above are summarised in Table 1.

Type of industry	Accidents	Accidents w. fatalities	% accidents w. fatalities	Fatalities	Fatalities / accident	Fatalities / accident w. fatalities
general chemicals manufacture	100	15	15.00	53	0.53	3.53
petrochemical	50	11	22.00	23	0.46	2.09
wholesale and retail storage	26	8	30.77	8	0.31	1.00
metal refining and processing	20	7	35.00	13	0.65	1.86
plastics and rubber manufacture	17	2	11.76	2	0.12	1.00
pesticides, pharmaceuticals	15	3	20.00	3	0.20	1.00
production and storage of explosives	12	9	75.00	36	3.00	4.00
power supply and distribution	11	1	9.09	2	0.18	2.00
food and drink	11	1	9.09	3	0.27	3.00
agriculture	8	2	25.00	4	0.50	2.00
waste treatment	8	0	0.00	0	0.00	
fairgrounds/amusements	6	1	16.67	1	0.17	1.00
paper manufacture	4	0	0.00	0	0.00	
handling & transport center	3	0	0.00	0	0.00	
timber and furniture	3	1	33.33	2	0.67	2.00
electronics and electrical engineering	2	0	0.00	0	0.00	
ceramics	1	0	0.00	0	0.00	
building and works of engineering	1	1	100.00	2	2.00	2.00
textiles, clothing and footwear	1	0	0.00	0	0.00	
general engineering	0	0		0		
mining activities	0	0		0		
not know not applicable	2	1	50.00	1	0.50	1.00
TOTAL	**301**	**63**	**20.93**	**153**	**0.51**	**2.43**

Table 1. Summary of number of accidents, accidents with fatalities and number of fatalities per industry type.

From the results shown in the previous Figures and in Table 1, the following analysis can be made.

- The general chemicals manufacture industry has had an oscillating tendency, constantly increasing the number of accidents for the period 1995-1998, and then decreasing constantly during 1998-2002, with a slight worsening of the situation in 2003 and reducing the number of accidents again in 2004. General chemicals manufacture is the type of industry with the highest number of accidents (100), but only 15 (15%) of those generated a fatality. It is however the type of industry with higher number of fatalities (53), mainly due to the fact that the Toulouse accident, which had 30 fatalities, was reported under this category.
- Accidents in petrochemical facilities are more likely to generate fatalities. 11 out of 50 accidents (22%) reported at least one casualty, for a total of 23 fatalities. The distribution of major accidents during the period analysed varies widely, from one single accident reported in 1995 and 2001, to 7 accidents in 1996 and 2004, and 8 accidents in 2002. Usually petrochemical sites involve handling of large quantities of flammable liquids. Whenever there is, for instance, a fire in this type of establishment, the common procedure is not to extinguish the fire, but to let all the released inventory burn to avoid explosion risks. Therefore, the amount of substances involved usually exceeds the limits fixed by the Seveso II Directive to determining the criteria for a major accident, which is the reason why the number of these events is high.
- Accidents in establishments dealing with the production and storage of explosives generate a lot of fatalities even though there are not many accidents in this type of industry. The reason for this is that it is a very regulated industry, therefore the number of accidents is low. However, due to the nature of the hazardous substances handled in these installations, usually highly explosive, nearly all accidents involve fatalities. The year 2000 was particularly tragic for pyrotechnic installations, with the Enschede accident generating 22 fatalities and another accident generating

3 deaths. Also the year 2002 was difficult, when 4 accidents occurred that generated 7 victims. The situation is similar with the metal refining and processing industry. 7 out of 20 accidents (35%) reported a fatality, generating a total of 13 fatalities, which indicates that the consequences of accidents in this type of industry are usually quite severe. Processes associated to metal refining involve toxic substances like cyanides, and extreme conditions such as heating processes at gas furnaces.

- Wholesale and retail storage, food and drink, plastics and rubber manufacture, pesticides and pharmaceuticals types of industries have seen a decrease in the number of accidents. In fact none of these types of industries reported accidents in the last two years of the analysis. The wholesale and retail industry, including the handling of hazardous substances such as LPG, reported 26 accidents, 8 of which generated at least 1 fatality (30.8%). LPG industries are nowadays well developed, with many standards and regulations which have led to better understanding of the risks and of the necessary management of these sites. However many of the activities related to this type of industry deal with loading or unloading procedures, which involve precise operations such as connection of flexible hoses, turning on pumps or opening and closing valves, which are usually performed by operators near the chemical substances involved (e.g. loading trucks, storage vessels and so on). So even though the number of accidents has been lowered, the risks still remain due to the nature of the activities, the quantities of the substances involved and the presence of operators.

2.4. Physical effects of the accidents.

In order to better understand the previous discussion regarding the gravity of the accidents, it is interesting to analyse the physical effects generated by those accidents (i.e. release, fire, and explosion) and to link them with the number of fatalities generated in the events studied. Figure 15 shows which one of the three effects were reported in the different accidents, grouped for each type of industry.

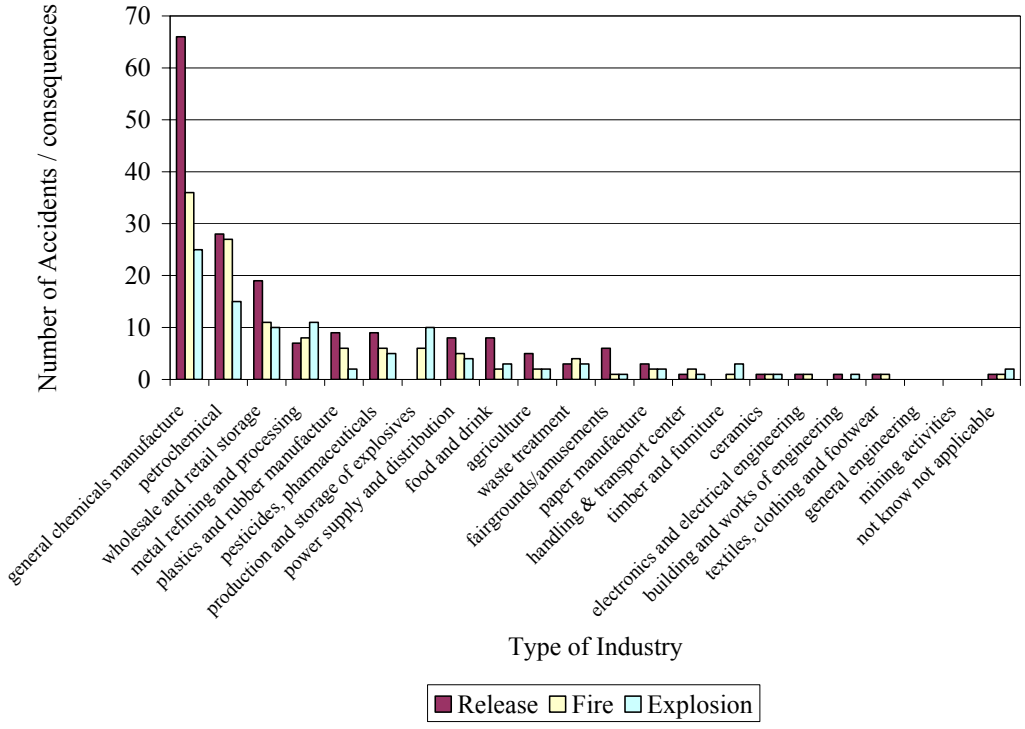

Figure 15. Number of physical effects reported for each type of industry[2].

[2] More than one consequence can be reported for each accident.

It can be seen that the release of chemical substances is the most common effect. A total of 176 releases were reported in the accidents analysed, as opposed to 122 fires and 100 explosions. However, looking at each type of industry, it can be seen that this is not always the case. For instance, in the case of petrochemical plants, the number of fires is almost the same as for releases. In the metal refining and processing industries, the number of fires and explosions is higher than that of releases, and in production and storage of explosives, there are indeed no releases reported. This suggests that it is necessary to check the consequences generated by each type of physical effect reported.

The MARS reports have been studied in detail in order to identify, for those accidents reporting fatalities or off-site injuries, which effect was the direct cause for the human consequences reported. Figure 16 shows the number of effects identified as generating a fatality for each industry type, and Figure 17 shows the number of fatalities generated by a specific effect.

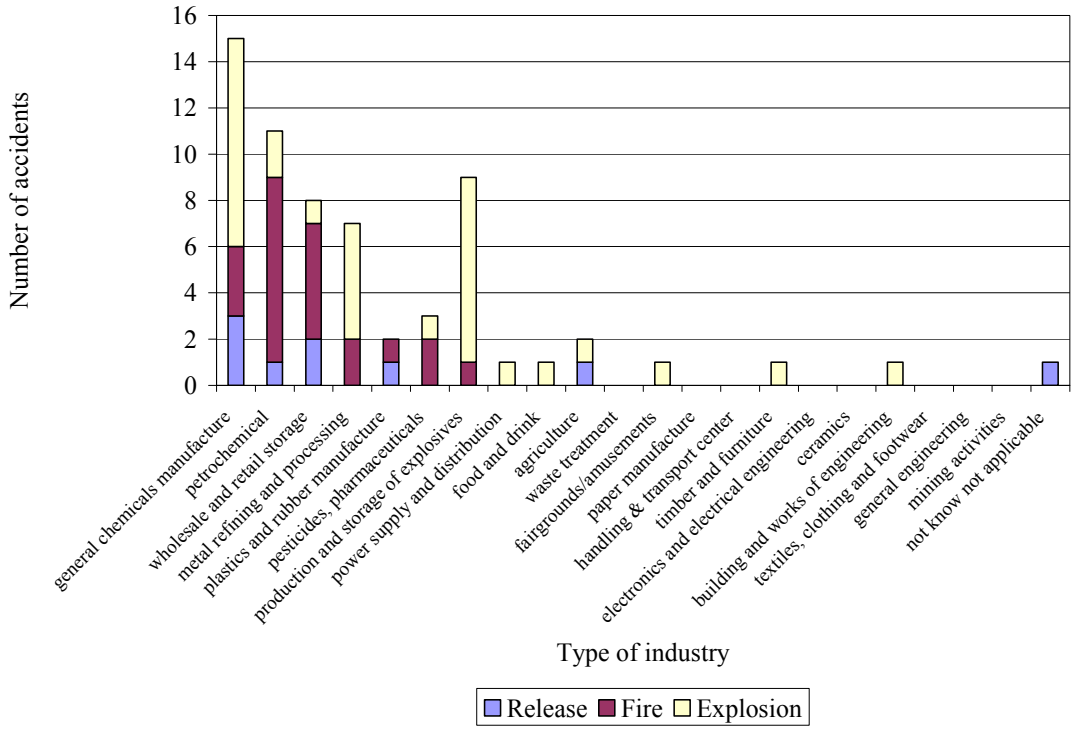

Figure 16. Number of accidents per industry type in which a reported effect led to fatalities.

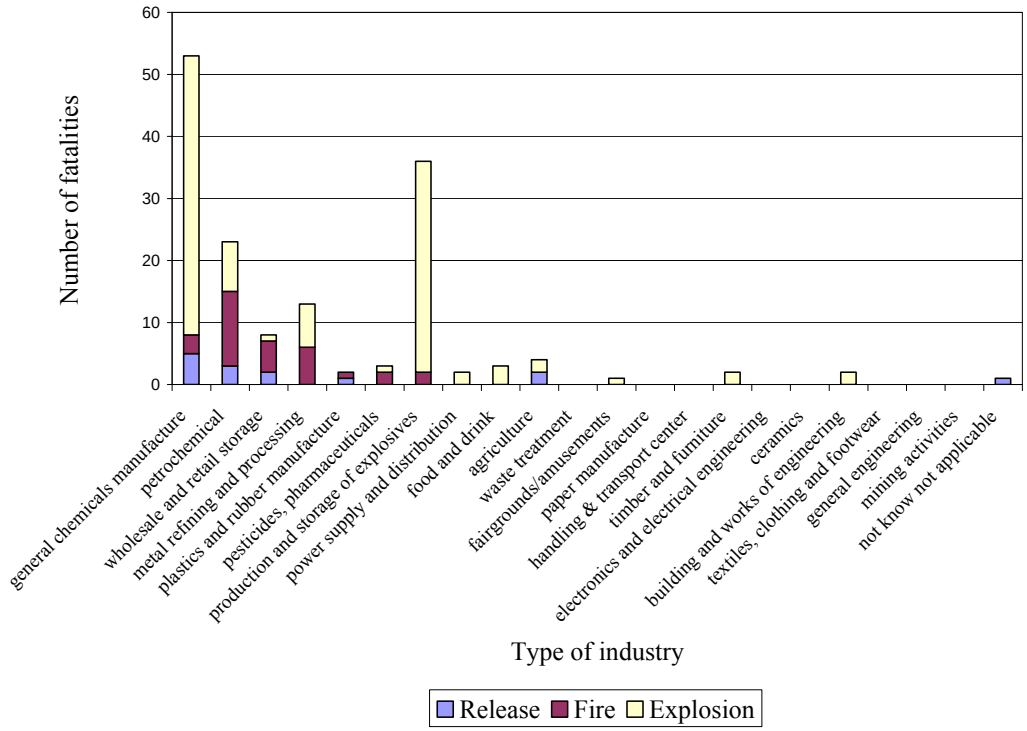

Figure 17. Number of fatalities per industry type generated by a specific effect.

Figures 18 and 19 show the same information as Figures 17 and 18 respectively, but distributed per year of the accidents.

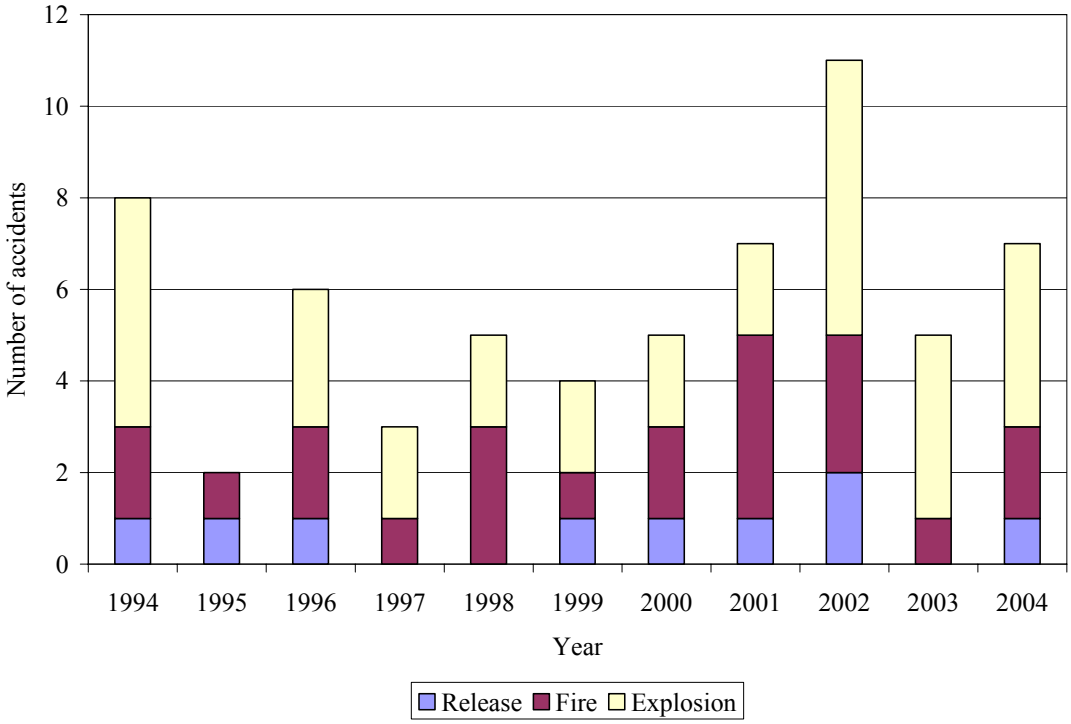

Figure 18. Number of accidents per year in which a reported effect led to fatalities.

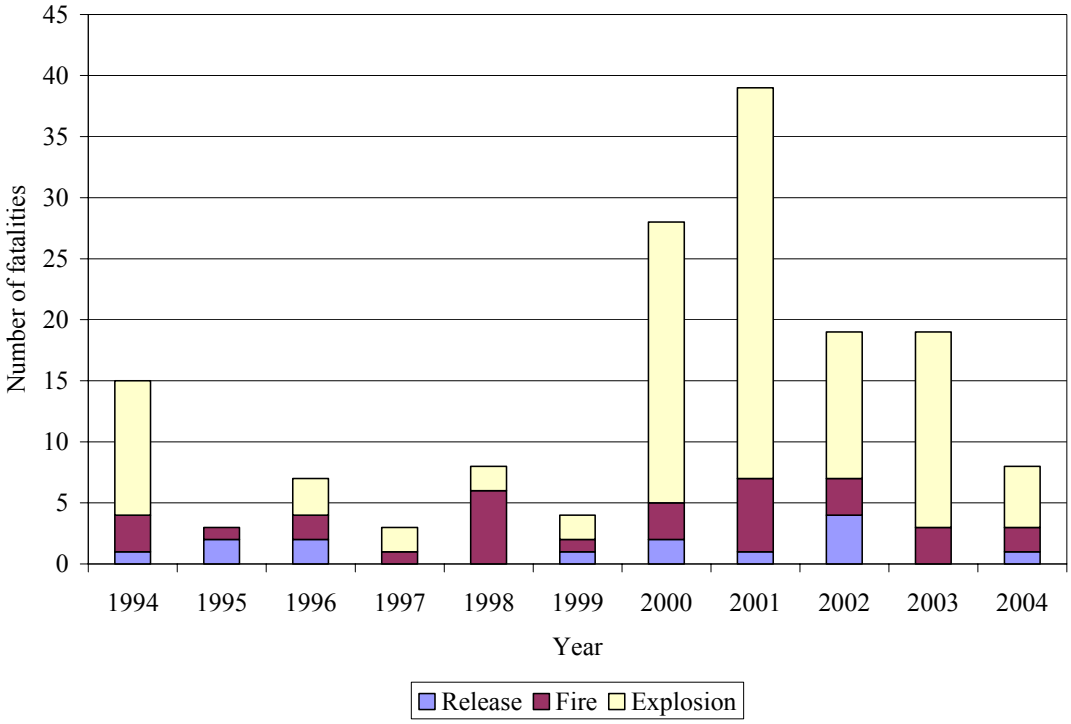

Figure 19. Number of fatalities per year generated by a specific effect.

Finally, Figures 20 and 21 show the total number and percentage of accidents in which the reported effect led to a fatality, and the total number and percentage of fatalities generated by each one of the effects reported.

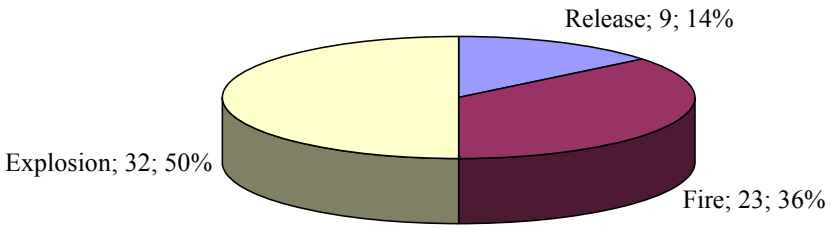

Figure 20. Number and percentage of accidents in which the effect led to fatalities.

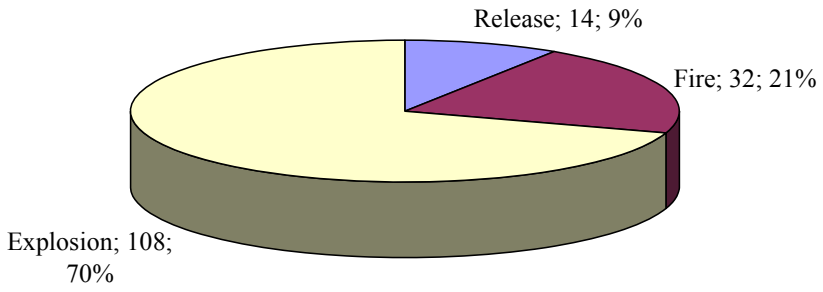

Figure 21. Number and percentage of fatalities generated by a specific effect.

It can be seen from the figures shown above that explosions are the type of effects that generate the highest number of fatalities (108) followed by fires (31) and releases (14). Also, an accident involving an explosion (32 out of the 63 accidents reporting fatalities) is more likely to generate fatalities than an accident generating a fire (22 out of 63) or a release (9 out of 63). The reason for this is the fact that an explosion gives very little time for operators in a process plant to react. Usually when an explosion occurs in a plant, if operators are nearby it is highly probable that they will be affected by the explosion due to a zero reaction time, and depending on the severity of the blast, it is likely that there will be fatalities. It can be seen in Figures 18 and 19, from the numbers corresponding to the general chemicals manufacture and production and the storage of explosives type of industries, and the years 2000 and 2001, that a high number of fatalities were generated due to explosions. This was the main effect, causing both fatalities and many injuries, involved in the Enschede and Toulouse tragedies.

A similar reasoning can be made with fires. If an operator is affected by a fire, he/she will suffer burns that, depending on the degree of exposure and the effectiveness of the response systems, may lead to a fatality. On the other hand, if a release is detected within a reasonable time and people have no movement restriction (i.e. not trapped in a building) there is usually enough time and opportunity for people to evacuate. That, of course, depends on the toxicity of the substance released and the preparedness of the personnel involved in the accident.

In order to analyse accidents in terms of human consequences, it is also interesting to look at the consequences of an event outside the limits of the industrial establishment. Figures 22, 23 and 24 show the number of accidents that generated consequences off-site, and the reported number of injuries generated by the accidents outside the establishment, depending on the type of effect generating human injuries. Again, it must be remembered that some reports do not specify the number of people injured, so the numbers in the figures below are not complete. It is indicated for which accidents no data was provided.

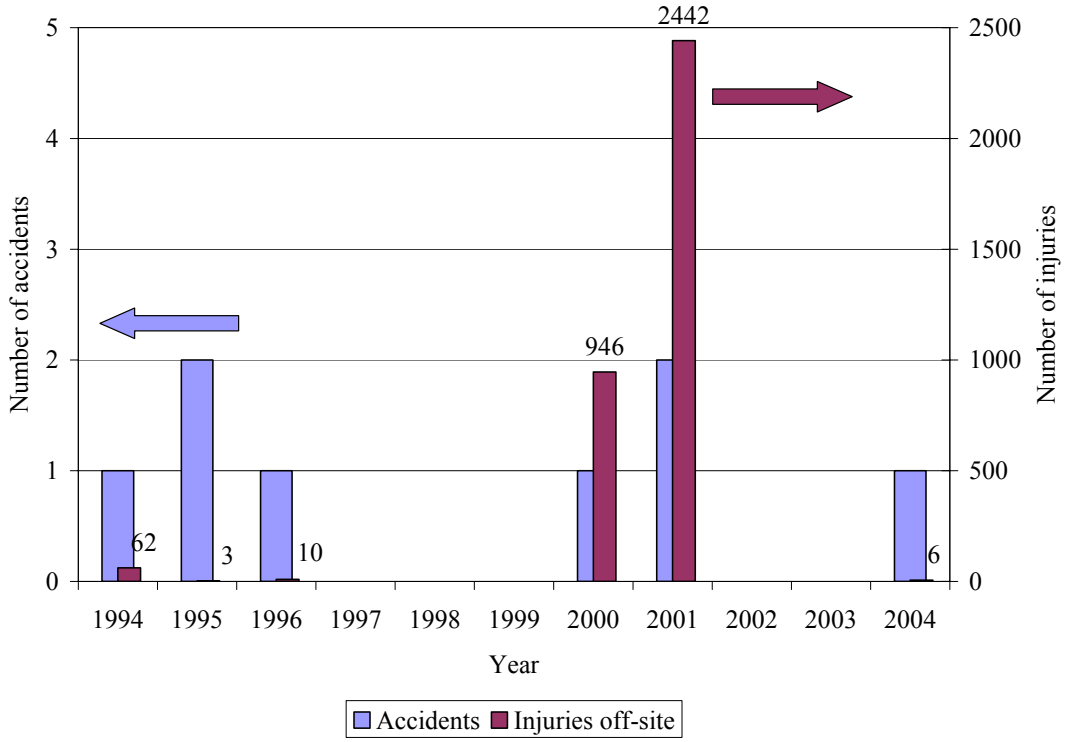

Figure 22. Consequences off-site of accidents involving explosions; showing number of injuries off-site.

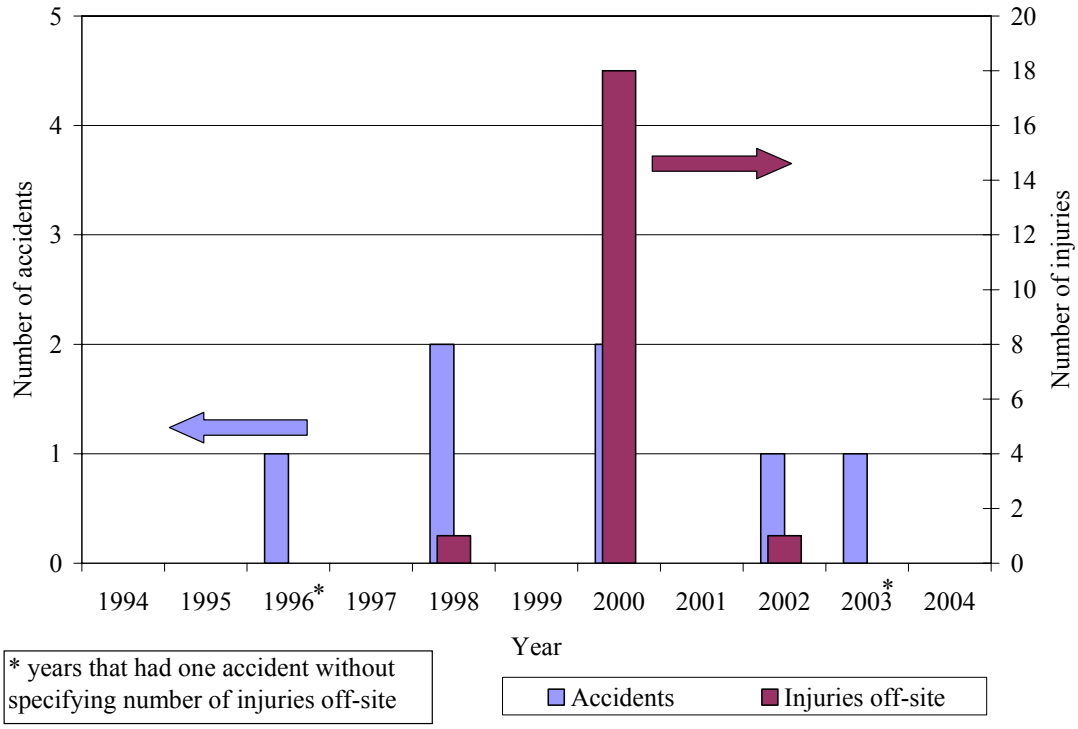

Figure 23. Consequences off-site of accidents involving fires

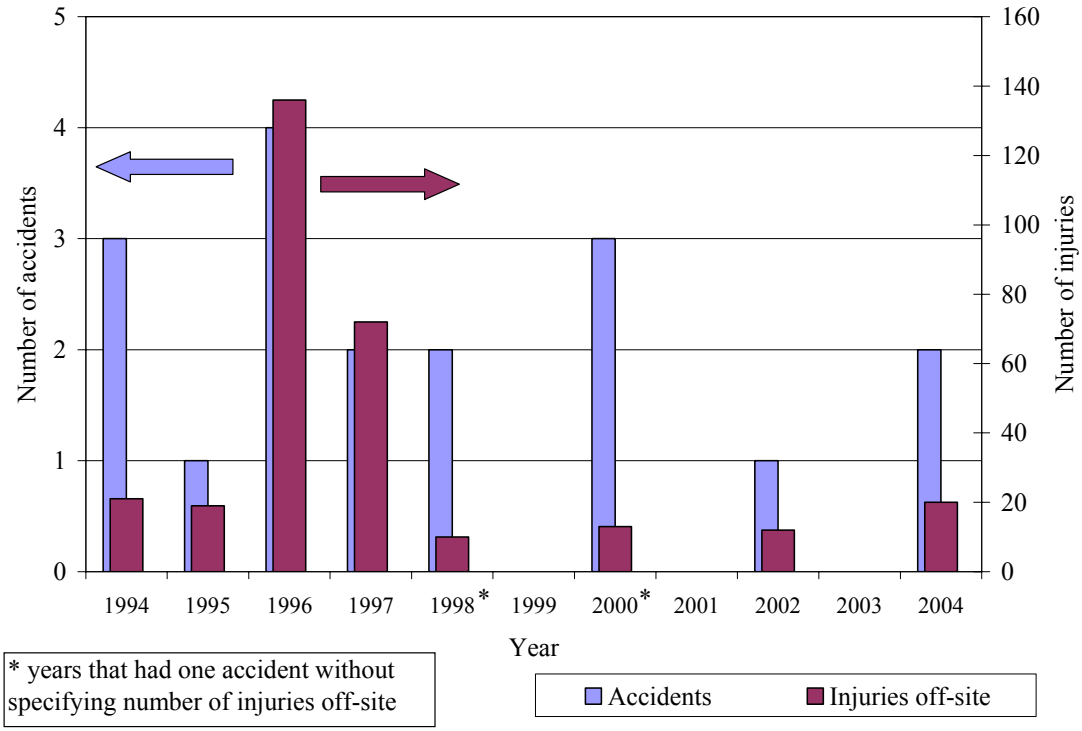

Figure 24. Consequences off-site of accidents involving releases

It can be seen that accidents generating consequences outside of industrial sites involved releases more than fires or explosions. Usually those accidents affect a lot of people (10 out of 16 accidents detailing the number of people involved affected 10 or more people). The reason for this is that, when a big chemical release generates a toxic cloud that is spread outside the plant limits, it is not easy for the population nearby to avoid a certain exposure to that cloud, which can have some harmful effects even if it is for a brief period of time. In the case of accidents with fires with consequences off-site, it must be stressed that in almost every one of the cases studied, the main effect suffered by the population was due to the dispersion of toxic fumes from the fire, generating respiratory problems. Only in one of those cases was there was a spill of crude oil into the rain water drain, reaching a nearby beach where it ignited, causing serious injuries to two persons, one of whom died because of the injuries.

Certainly, consequences of large accidents involving fires and explosions are extremely serious. 5 of the total 301 accidents analysed reported fatalities off-site. In 3 cases the fatalities were due to an explosion, while in the other 2 the effect involved was a fire. Again, the effects of the Enschede and Toulouse accidents effects are emphasised in Figure 23 (years 2000 and 2001) since the main consequences were due to the explosions that took place in those accidents.

Finally, Table 2 summarizes the numbers reported for the effects involved in the accidents analysed, the effects that led to fatalities, and the number of fatalities associated to the relevant effect per industry type.

Type of industry	Accidents	Rel.	Fire	Exp.	Accidents w. fatalities	Rel.	Fire	Exp.	Fatalities	Rel.	Fire	Exp.
general chemicals manufacture	100	66	36	25	15	3	3	9	53	5	3	45
petrochemical	50	27	26	14	11	1	8	2	23	3	12	8
wholesale and retail storage	26	19	11	10	8	2	5	1	8	2	5	1
metal refining and processing	20	7	8	11	7	0	2	5	13	0	6	7
plastics and rubber manufacture	17	9	6	2	2	1	1	0	2	1	1	0
pesticides, pharmaceuticals	15	9	6	5	3	0	2	1	3	0	2	1
production and storage of explosives	12	0	6	10	9	0	1	8	36	0	2	34
power supply and distribution	11	8	5	4	1	0	0	1	2	0	0	2
food and drink	11	8	2	3	1	0	0	1	3	0	0	3
agriculture	8	5	2	2	2	1	0	1	4	2	0	2
waste treatment	8	3	4	3	0	0	0	0	0	0	0	0
fairgrounds/amusements	6	6	1	1	1	0	0	1	1	0	0	1
paper manufacture	4	3	2	2	0	0	0	0	0	0	0	0
handling & transport center	3	1	2	1	0	0	0	0	0	0	0	0
timber and furniture	3	0	1	3	1	0	0	1	2	0	0	2
electronics and electrical engineering	2	1	1	0	0	0	0	0	0	0	0	0
ceramics	1	1	1	1	0	0	0	0	0	0	0	0
building and works of engineering	1	1	0	1	1	0	0	1	2	0	0	2
textiles, clothing and footwear	1	1	1	0	0	0	0	0	0	0	0	0
general engineering	0	0	0	0	0	0	0	0	0	0	0	0
mining activities	0	0	0	0	0	0	0	0	0	0	0	0
unknown / not applicable	2	1	1	2	1	1	0	0	1	1	0	0
	301	176	122	100	**63**	9	22	32	**153**	14	31	108

Table 2. Summary of number of accidents, effects, effects leading to fatalities and number of fatalities related to a specific effect, per type of industry.

It is interesting to notice how, even though in general explosions have the most serious effects, for some specific types of industries the situation is different. For instance, in petrochemical and in wholesale and retail storage establishments, there more are fatal accidents involving fires. This is usually related to the characteristics of the substances handled in those establishments, which are usually more flammable than explosive, hence more likely to generate fires than explosions. Also, this type of installation can have a high degree of automation in their processes, which leads to a reduced presence of operators on the plant.

2.5. Chemical substances involved in the accidents.

Finally, the substances involved in the accidents have been analysed. Figure 26 shows the number of substances reported according to the MARS classification system.

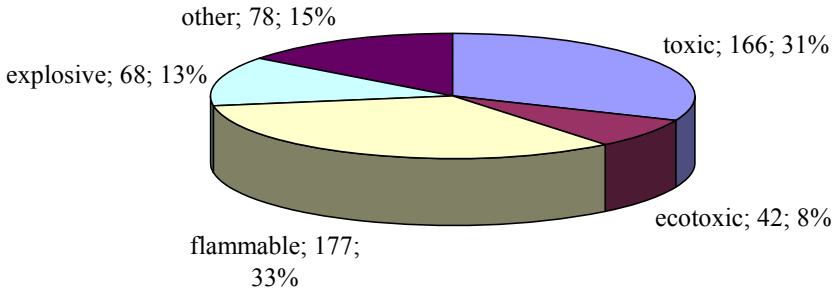

Figure 26. General classification of substances reported to MARS.

Table 3 shows the most common substances involved in the accidents reported to MARS, and the number of times they have been reported for the different types of industries.

Type of Industry	LPG	crude & nafta	HCl	natural gas	Cl_2	NH_3	solvents
general chemicals manufacture	8	2	9	1	7	1	5
petrochemical	14	20	0	3	0	1	0
wholesale and retail storage	7	4	0	0	1	0	3
metal refining and processing	4	0	1	2	1	0	0
plastics and rubber manufacture	3	0	1	0	0	0	0
pesticides, pharmaceuticals	0	0	2	0	0	0	0
power supply and distribution	1	0	1	7	0	0	0
food and drink	0	0	1	0	0	5	2
agriculture	0	0	0	0	0	3	0
waste treatment	1	0	0	0	1	0	0
fairgrounds/amusements	1	0	0	0	3	2	0
electronics and electrical eng.	0	0	1	0	0	0	0
building and works of engineering	0	0	1	0	0	0	0
TOTAL	39	24	17	13	13	12	9

Table 3 (1/2). Main substances reported per industry type.

Type of Industry	HF	H_2S	CO_X	H_2	PVC	SO_X	NO_X	O_2	benzene
general chemicals manufacture	2	1	2	3	3	3	2	0	2
petrochemical	2	3	0	2	0	0	0	0	1
wholesale and retail storage	0	1	0	0	0	0	0	1	0
metal refining and processing	1	0	3	0	0	0	0	1	0
plastics and rubber manufacture	0	0	0	0	2	0	0	0	0
pesticides, pharmaceuticals	0	0	0	0	0	0	1	0	0
agriculture	0	0	0	0	0	0	1	0	0
paper manufacture	0	0	0	0	0	1	0	0	0
handling & transport center	0	0	0	0	0	0	0	0	1
electronics and electrical eng.	0	0	0	0	0	0	0	1	0
unknown / not applicable	0	0	0	0	0	0	0	1	1
TOTAL	5	5	5	5	5	4	4	4	4

Table 3 (2/2). Main substances reported per industry type.

Table 4 presents the substances that were involved in the accidents that generated fatalities, the type of industry involved, the main effect involved and the total number of fatalities[3].

Substance	Type of Industry	Effect	Fatalities
Residues of ammonium nitrate	general chemicals manufacture	Explosion	30
Storage of fireworks	prod. and storage of explosives	Explosion	22
Unleaded petrol	petrochemical	Explosion	7
Dynamite	general chemicals manufacture	Explosion	4
Gasoline	petrochemical	Fire	4
Explosive substances	prod. and storage of explosives	Explosion	4
Water vapour	food and drink	Explosion	3
Natural gas and fuel gas	general chemicals manufacture	Explosion	3
Carbon monoxide	metal refining and processing	Fire	3
Methane	metal refining and processing	Explosion	3
Oxygen	metal refining and processing	Fire	3
Hydrogen sulphide	petrochemical	Release	3
Pyrotechnic substances	prod. and storage of explosives	Explosion	3
Ammonia	agriculture	Release	2
Explosive dust/air compounds	agriculture	Explosion	2
HCl, asphalt	building and works of eng.	Explosion	2
Hydrogen sulphide	general chemicals manufacture	Release	2
TiCl4 HCl	general chemicals manufacture	Release	2
Carbon monoxide boric acid	general chemicals manufacture	Explosion	2
Pyrotechnic substances	general chemicals manufacture	Explosion	2

Table 4 (1/2). Substances involved in accidents leading to fatalities, type of industry, direct effect related to the fatality and number of fatalities.

[3] MARS reports do not always give complete details as to the substances involved in the accidents, and sometimes only a generic description such as ‘explosive substances’ is given.

Substance	Type of Industry	Effect	Fatalities
Iron sulphide	Petrochemical	Fire	2
HCl, KOH, H2SO4, natgas	power supply and distribution	Explosion	2
Gun- powder	prod. and storage of explosives	Fire	2
Explosive dust / air mixtures	timber and furniture	Explosion	2
Propane	fairgrounds/amusements	Explosion	1
Silicone in toluene solution	general chemicals manufacture	Explosion	1
Propanol and hydrogen	general chemicals manufacture	Fire	1
Explosive substances	general chemicals manufacture	Explosion	1
Aluminium, NaOH	general chemicals manufacture	Fire	1
Toluene	general chemicals manufacture	Explosion	1
Hydrogen cyanide	general chemicals manufacture	Release	1
Tetrahydrofurane (THF)	general chemicals manufacture	Fire	1
Methyl-cyclohexane	general chemicals manufacture	Explosion	1
Aluminium	metal refining and processing	Explosion	1
LPG	metal refining and processing	Explosion	1
TiCl4	metal refining and processing	Explosion	1
Explosive gases	metal refining and processing	Explosion	1
Sodium borohydride	pesticides, pharmaceuticals	Explosion	1
Toluene	pesticides, pharmaceuticals	Fire	1
Flammable	pesticides, pharmaceuticals	Fire	1
Gasoline	petrochemical	Fire	1
Gasoline, LPG	petrochemical	Fire	1
Methyl tertiary butyl ether	petrochemical	Explosion	1
Crude oil	petrochemical	Fire	1
Heavy fuel oil	petrochemical	Fire	1
Petroleum spirits	petrochemical	Fire	1
No details available	petrochemical	Fire	1
LPG and natural gas	petrochemical	Fire	1
Propane	plastics and rubber manufacture	Fire	1
Toxic substance	plastics and rubber manufacture	Release	1
Explosive substance	prod. and storage of explosives	Explosion	1
Explosive substance	prod. and storage of explosives	Explosion	1
Explosive substance	prod. and storage of explosives	Explosion	1
Propellant	prod. and storage of explosives	Explosion	1
Explosive substance	prod. and storage of explosives	Explosion	1
Benzene	not specified	Release	1
Phenol	wholesale and retail storage	Release	1
Petroleum spirit	wholesale and retail storage	Explosion	1
Butane	wholesale and retail storage	Fire	1
Propane	wholesale and retail storage	Fire	1
Various flammable solvents	wholesale and retail storage	Fire	1
Flammable substances	wholesale and retail storage	Fire	1
Oxygen	wholesale and retail storage	Fire	1
Hydrogen sulphide	wholesale and retail storage	Release	1

Table 4 (2/2). Substances involved in accidents leading to fatalities, type of industry, direct effect related to the fatality and number of fatalities.

Table 5 shows the accidents in which consequences were reported off-site. The substance involved, the type of industry, the main effect leading to injuries, the number of injuries reported ('nr' is shown in the cases were no specific number of injuries was reported) and the number of fatalities off-site are shown.

Substance involved	Type of industry	Effects	Injuries off-site	Fatalities off-site
Natural gas	power supply and distribution	Explosion	62	1
Parachloroaniline	general chemicals manufacture	Release	2	0
Trichloro (methyl) silane	general chemicals manufacture	Release	18	0
Ammonia	agriculture	Release	1	0
Phenol-FMA	plastics and rubber manufacture	Explosion	1	0
Flammable liquids.	wholesale and retail storage	Explosion	2	0
Ammonia	food and drink	Release	19	0
Ammonia	fairgrounds/amusements	Release	36	0
Chlorine	metal refining and processing	Release	7	0
Butane	wholesale and retail storage	Explosion	10	0
Hydrogen chloride	pesticides, pharmaceuticals	Release	76	0
Sulphuric acid	general chemicals manufacture	Release	17	0
Epichlorohydrin	general chemicals manufacture	Fire	nr	0
Ammonia	fairgrounds/amusements	Release	4	0
Hydrochloric acid	food and drink	Release	68	0
Bromine	general chemicals manufacture	Release	nr	0
Gasoline	petrochemical	Fire	0	4
Hydrogen chloride	general chemicals manufacture	Release	10	0
Crude oil	petrochemical	Fire	1	1
$TiCl_4$, hydrogen chloride	general chemicals manufacture	Release	3	0
Pvc, hydrogen chloride	general chemicals manufacture	Fire	13	0
Synthetic resins	general chemicals manufacture	Fire	5	0
Phenylphosphine	general chemicals manufacture	Release	nr	0
Hydrogen chloride	general chemicals manufacture	Release	10	0
Pyrotechnics	prod. and storage of explosives	Explosion	946	18
Ammonium nitrate	general chemicals manufacture	Explosion	2440	8
Ethane/propane/butane	petrochemical	Explosion	2	0
Fertilizers	general chemicals manufacture	Fire	1	0
$TiCl_4$, hydrogen chloride	general chemicals manufacture	Release	12	0
Dichlorisocyanurate	general chemicals manufacture	Fire	nr	0
LPG, natural gas	power supply and distribution	Explosion	6	0
Chlorine	general chemicals manufacture	Release	2	0
Alkyl bromides, HBr	waste treatment, disposal	Release	18	0

Table 5. Substances involved in accidents leading to injuries off-site, type of industry, direct effect related to the injury and number of injuries off-site.

From the data shown in Tables, 3, 4 and 5, the following remarks can be made:

- Table 4 supports the conclusion that explosions are the most serious accidents on-site, as 9 out of the 13 accidents with more than 2 fatalities were explosions, while 3 were fires and only 1 was a release.
- LPG and petroleum related substances are the most common substances involved in the accidents analysed. These substances are mainly dealt with at petrochemical sites, as well as general chemical manufacture and wholesale and retail storage establishments, although they may also be used for fuel in other industries. Hydrogen chloride is also found in many of the accidents, being involved in a wide range of processes, as well as chlorine and ammonia. Natural gas is involved mainly in power supply and distribution facilities.
- Common chemical substances involved in the accidents analysed are hydrogen, oxygen, hydrogen fluoride, hydrogen sulphide, and oxides of carbon, sulphur and nitrogen. It is interesting to notice the presence of 5 cases involving handling or production of polyvinylchloride.
- There is a wide variety of substances involved in accidents leading to fatalities. Table 4 is useful to relate substances typically involved in fatal accidents to specific types of industries and the effects associated to them. It can be seen, for instance, that all the accidents with fatalities at production and storage of explosives dealt with explosive substances; for petrochemical sites, LPG and petroleum derived products are the most common substances leading to fatal fires. For the rest of industry types, however, there is a broad spectrum of substances involved.
- Toxic releases are the most frequent effect in accidents generating consequences off-site. The use of common chemicals is usually involved in these kinds of accidents. In this sense, hydrogen chloride was involved in 7 of 33 (21.2%) of the accidents reporting human injuries outside an establishment. 5 of those accidents took place at general chemicals manufacture establishments, one at food and drink production plants, and another one during production of pesticides or pharmaceuticals.
- 3 explosions involving LPG resulted in injuries outside the establishment where the accidents took place; 1 at a power supply and distribution plant, 1 at a petrochemical establishment and 1 at a wholesale and retail storage site; natural gas was involved in 2 explosions at 2 power supply and distribution facilities; petroleum derived products generated 2 fires at 2 petrochemical establishments generating consequences off-site.

3. Conclusions.

The analysis performed on major accidents that occurred in EU15 countries for the period 1994-2004 shows that there is an ongoing need to improve the safety level of industrial installations in Europe. On the positive side, there has been a progressive reduction in the number of major accidents reported to MARS since the implementation of the Seveso II Directive in 1996. However, some of those accidents are still generating serious consequences for the personnel working at those establishments as well as for the external population. The European Commission, especially through the research activities carried by the Major Accident Hazards Bureau of the JRC, continues its efforts to improve the legislation regarding the safety of industrial plants. As an example, the amendment to the Seveso II Directive issued in 2003, which was in part launched as a response to the Enschede and Toulouse tragedies that happened in the period studied for the present analysis.

The number of major accidents reported since 1996 has been reduced in periods of three years. In each period the number of accidents was reduced progressively, followed by an abrupt increase of reported events every three years. This fact could suggest that there are cyclical variations in the management of safety of some process industries, probably due to an excessive relaxation in risk perception after periods with fewer accidents. Further analysis on the evolution of accidents during the future years will be needed in order to confirm this trend. The operators aim should be the implementation of a safety culture at industrial establishments, in order to achieve a continuous improvement of the quality of safety management, and accident reporting and analysis is an important part of this.

The present analysis has related the consequences of the accidents with the types of industries and substances involved, as well as to the physical effects generated. It has been determined that accidents involving explosions are the ones that generate the most severe consequences, even though for certain types of industries like petrochemical establishments, fires are of more concern. On the other side, accidents involving disturbances for the external population are usually related to toxic releases of general chemical products such as ammonia or hydrogen chloride.

The severity of the accidents analysed has been categorised depending on the data on fatalities as well as injuries to the external population. However, the accidents reported to the MARS database allow other criteria to be used, like the amounts of monetary losses or the severity of environmental consequences. Similar analysis to the one presented in this report could be interesting to relate the types of substances, industry types or physical effects related to those criteria (e.g. effects of explosions on property damage, or effects of toxic releases and the ecological harm generated).

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Title: Analysis of Major Accidents Reported to the MARS Database during the period 1994-2004

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Abstract
The analysis of past accidents in process industries is a useful method for identifying common aspects regarding the causes that triggered such accidents. The Major Accident Hazards Bureau of the European Commission's Joint Research Centre (JRC) has a long tradition in the analysis of "major accidents" reported to the MARS database in accordance with the Seveso II Directive requirements. This report presents the results of the analysis performed on a series of accidents reported to the MARS database. The analysis is limited to those events reported as major accidents occurred in EU 15 countries during the period 1994-2004.

The objective of the present report is to obtain trends in the evolution of the accidents for the period analysed, as well as to establish relations between different aspects regarding the accidents studied. In particular, the aspects on which the present analysis has focused are:

- Evolution of the number of major accidents per year.
- Consequences of the accidents, in terms of overall fatalities and number of people injured outside the establishment concerned.
- Types of industries involved in the accidents as stated in the MARS reports.
- Physical consequences resulting from the accidents.
- The main chemical substances involved in the accidents.

The previous items have been interrelated in an attempt to establish correlations between the different parameters. For instance, for each type of industry studied, the number of accidents involving human fatalities per year will be shown, specifying what were the physical effects and the chemical substances involved. The main parameter of interest selected to highlight the accidents analysed has been the number of fatalities or injuries outside the industrial establishment, but other parameters included in the MARS reports such as economic losses or environmental damage could also be used for similar analyses in the future.

The analysis performed shows that there is a cyclical oscillation in the number of accidents reported to MARS since the implementation of the Seveso II Directive in 1996. Since that date, there appear to be periods of 3 years in which there is a progressive decrease in the number of accidents, with an abrupt increase of reported events at the end of each cycle. The present analysis also proves that accidents involving explosions are the ones that generate the most severe consequences, even though for certain types of industries, fires are of greater concern. On the other hand, accidents creating disturbances for the external population are usually related to toxic releases of general chemical products such as ammonia or hydrogen chloride. This report quantifies the accidents of each type that have been reported to MARS and shows their evolution over the years in the period analysed.

The mission of the JRC is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private or national.